

THE POST - GLACIAL DEVELOPMENT
OF LAKE TRUMMEN, SMÅLAND, CENTRAL
SOUTH SWEDEN

REGIONAL VEGETATION DEVELOPMENT,
WATER LEVEL DEVELOPMENT AND
PALAEOLIMNOLOGIC DEVELOPMENT

By GUNNAR DIGERFELDT

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This paper is a summary of unpublished investigations on the Post-Glacial development of Lake Trummen. The investigations were started in 1964 and have comprised the following parts: I. The regional vegetation development, II. The water level development, III. The palaeolimnologic development. They are planned to be published together in a monographic paper.

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DESCRIPTION OF THE INVESTIGATION AREA

The situation of Lake Trummen ($56^{\circ}52'N$, $14^{\circ}50'E$) appears from the maps in Figs. 1-2. The lake is situated at the town of Våxjö in the central part of the oligotrophic South Swedish Highlands. The bedrock in this region is formed by Archaean granites and mostly covered by sandy and silty till. Due to the Archaean origin, the soils are primarily poor in lime and basic minerals.

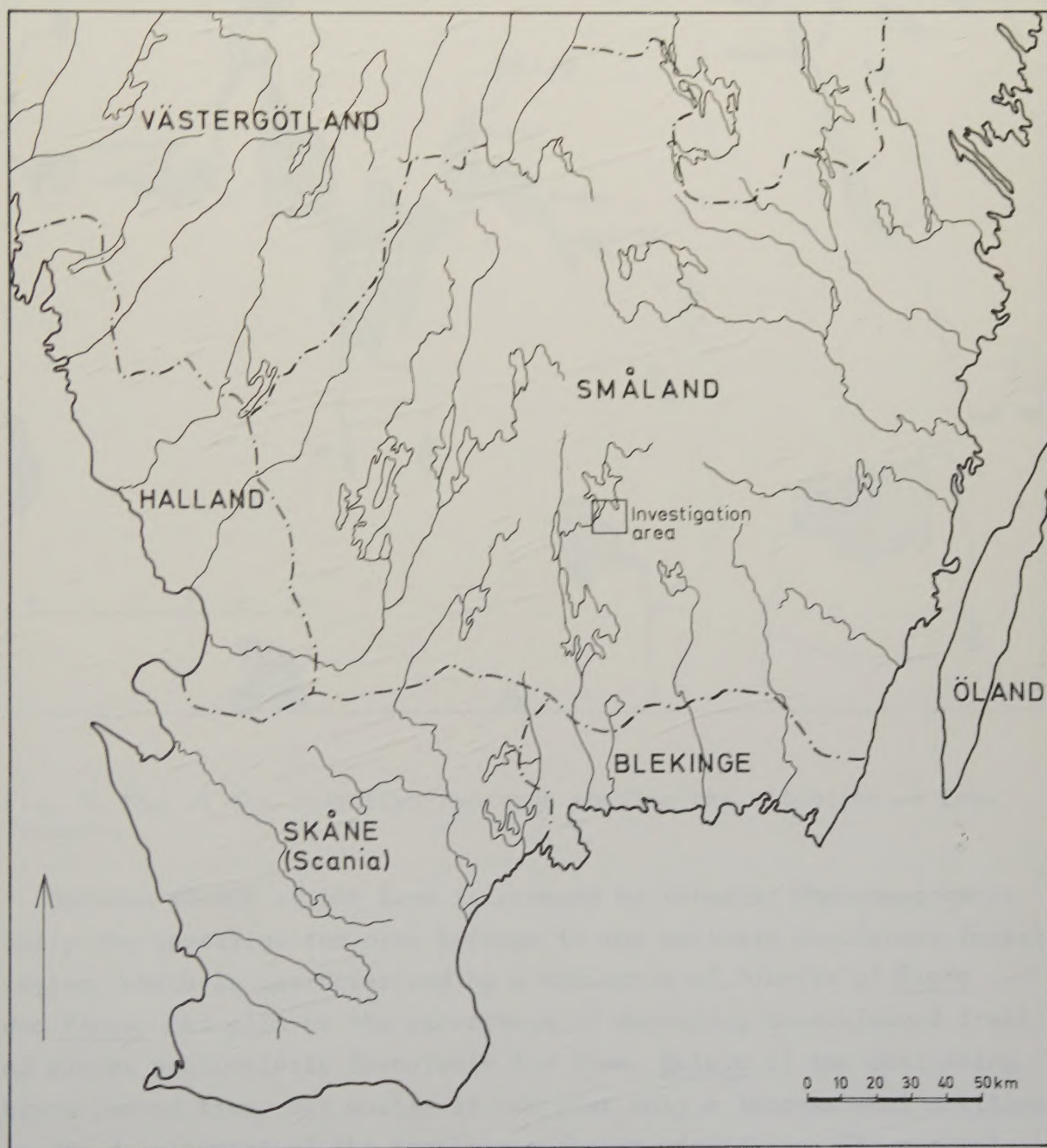


Fig. 1. Map of South Sweden showing the situation of the investigation area.



Fig. 2. Map of the investigation area showing the situation of Lake Trummen.

Between 40-50% of the land is covered by forests. Phytogeographically the investigation area belongs to the southern coniferous forest region, which is characterized by a dominance of forests of Picea and Pinus, but also by the occurrence of demanding broad-leaved trees on places particularly favourable for them. Betula is the dominating broad-leaved tree, but mostly it occupies only a successional position in the development of the coniferous forest vegetation. The nemoral broad-leaved trees Quercus, Tilia, Ulmus and Fraxinus are generally found as restricted groves or stands, and the same is true of Fagus.

Up until the beginning of the present century Lake Trummen was a typical oligotrophic lake characteristic for the region. However, since then the lake was utilized as recipient of a successively increased quantity of sewage and industrial water, which resulted in that it became heavily polluted. Lake Trummen exhibited all the characteristics of an overexploited recipient. In 1959 the sewage discharge was mainly stopped, but in spite of this the conditions in the lake did not become noticeably improved. Some years ago a plan for a thorough restoration of the lake was presented (Björk 1966, 1968). The restoration should comprise in the first place a removal by pumping of the sediment which has been deposited during the recipient period. This sediment consists of FeS-coloured and very nutrient-rich gyttja, which acts as a source of autochthonous supply of nutrients and seriously impedes the recovery of the lake. Intensive multi-disciplinal ecologic - limnologic, microbiologic, plant and animal ecologic and geologic - investigations for a more precise planning of the restoration were started in 1968. A report of these preliminary investigations, in which also the present author was partly engaged, was presented in 1969 (Trummen-projektet. Förundersökningarna. Slutrapport. Ed. Lettevall, U.). The sediment pumping began in 1970 and will be completed in 1971.

I. INVESTIGATION ON THE REGIONAL VEGETATION DEVELOPMENT

The investigation on the regional vegetation development is based on pollen analysis of a main profile from the central and deepest part of the lake. In addition a shorter complementary profile has been analyzed.

Zoning of the pollen diagrams and radiocarbon dating

The zoning of the pollen diagrams follows the Scanian zone system (T. Nilsson 1935, 1961). This zone system, as shown by T. Nilsson (1948), is for the most part directly transferable to the Danish zone system (Jessen 1935, 1937, 1938). As concerns most of the zone boundaries, it was possible to use mainly the same criteria as in Scanian diagrams. The revisions which have been necessary are connected with the generally smaller representation of the nemoral trees Ulmus, Tilia, Quercus, and Fraxinus, and as concerns the youngest zones the different appearance and representation of Picea and Fagus.

The pollen zone boundaries and other important pollen-floristic levels in the diagrams have been radiocarbon dated. In all 30 radiocarbon

datings have been carried out, which are published in the dating lists Lund I, II and III (Håkansson 1968-1970).

The limited regional relevance and applicability of pollen zone systems based on phytogeographic criteria are stressed. One natural limit is determined by the regional changes in the composition and development of vegetation. Another limit may be set by the successive and delayed immigration of the trees, which may lead to a more or less serious metachroneity which complicates regional correlations.

The zone boundary datings from Lake Trummen are compared in Fig. 3 with the ages given from Scania by T. Nilsson (1964 a) and from Blekinge by Berglund (1966 a, b). T. Nilsson (op.cit.) has in turn compared the

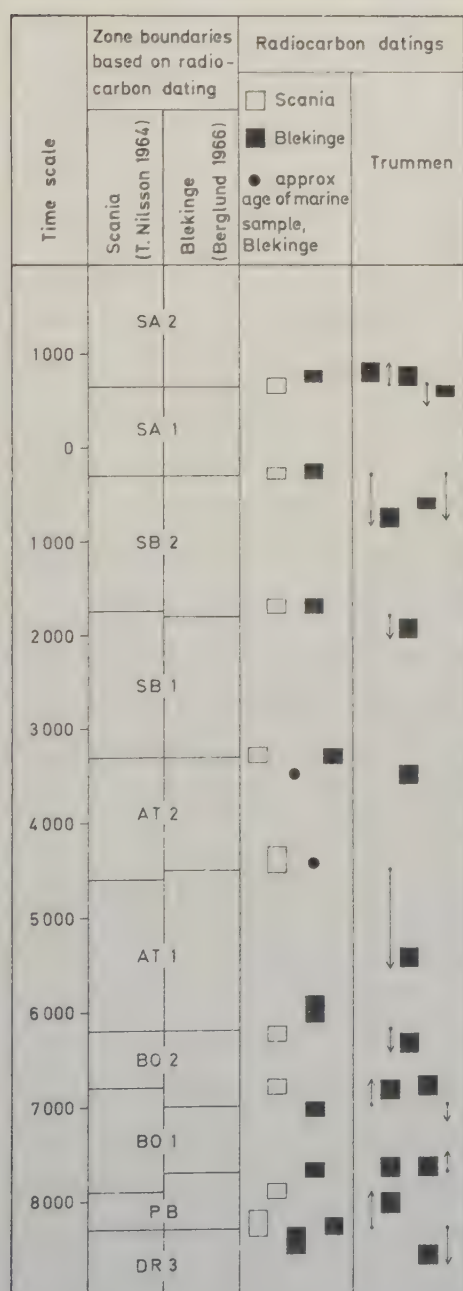


Fig. 3. Comparison of radiocarbon datings of zone boundaries in Scania, Blekinge and Lake Trummen. The radiocarbon dates are indicated with the statistical standard deviation (1 SD). As concerns the datings in Lake Trummen an arrow indicates the stratigraphic level of the samples, above or below the actual zone boundary. DR 3, Younger Dryas period; PB Pre-Boreal period; BO 1-2, Early and Late Boreal periods; AT 1-2, Early and Late Atlantic periods; SB 1-2, Early and Late Sub-Boreal periods; SA 1-2, Early and Late Sub-Atlantic periods.

Scanian ages with available datings from other countries in northwestern Europe. The datings from Lake Trummen in most cases agree well with those from Scania and Blekinge. However, the zone boundary AT 1/AT 2 has given an obviously different age, and this ought to be checked by further datings. The problem about the great difference in age between the datings from immediately below and above the boundary DR 3-PB/PB is left open until a planned investigation on the Late-Glacial development has been carried out. A probable influence by methodic errors on some of the datings has been discussed.

Interpretation of the vegetation development

Based on the pollen diagrams, the successional development of the regional vegetation has been interpreted and discussed. The regionally characteristic feature in comparison with southernmost Sweden is as stressed the generally smaller representation of the nemoral forest constituents Ulmus, Tilia, Quercus and Fraxinus, and as concerns the youngest periods the different appearance and representation of Fagus and Picea.

As a result of climatic improvement a pioneer forest vegetation of Betula was rapidly immigrating during the transition period DR 3-PB and the beginning of the Pre-Boreal period. In this pioneer vegetation characteristically also Juniperus was found - the culmination of this shrub indicates the transition between the previous Late-Glacial tundra vegetation and the immigrating Post-Glacial temperate forest vegetation.

The forests were during the beginning of the Pre-Boreal period still more or less open, and survivals from the Late-Glacial open vegetation persisted in places. Pinus immigrated at latest around the middle of the Pre-Boreal period. Mixed forests with Betula and Pinus became common, and in these the representation of Pinus was successively increased.

The beginning of the Early Boreal period is characterized by the immigration of Corylus. Corylus culminated later on during this period, but for both edaphic and climatic reasons it had even then a rather limited occurrence. Forests with Betula and particularly Pinus were distinctly dominating during both the Early and Late Boreal periods. However, a strong and continuous decrease of Pinus indicates a beginning restriction during the latter period.

The vegetational development during the Early and Late Boreal periods was dynamic in the way that probably all the broad-leaved trees of the later succeeding hypsithermal climax forest vegetation - Ulmus, Tilia,

Quercus and Fraxinus - were then successively immigrating. The immigration of Alnus characterizes the boundary between the Early and Late Boreal periods. Scattered stands of Ulmus may have immigrated already during the end of the Pre-Boreal period, Quercus during the Early Boreal period. The frequencies in the beginning are very low, but around the transition to the Late Boreal period both these trees show a slight but distinct increase. The beginning of the Post-Glacial culmination of Ulmus is found during the earlier part of the latter period and maximum frequencies are reached during the later part. Scattered stands of Tilia and perhaps also of Fraxinus may have immigrated during the end of the Late Boreal period.

Thus, at the beginning of the Early Atlantic period, probably all broad-leaved trees of the hypsithermal climax forest were represented in the region. However, forest with Pinus and Betula were still distinctly dominating. Towards the end of the Early Atlantic period and during the beginning of the Late Atlantic period, there was a distinct expansion of Quercus and Tilia. After this expansion the previous more dynamic stage of the forest development appears to have ceased, or to have become moderated. In regard to forest succession a climax stage was reached, which on the whole was characterized by a natural balance between the different forest communities. Towards the end of the Late Atlantic period there was a further expansion of Quercus, simultaneously with a distinct decrease of Pinus.

The boundary between the Late Atlantic and the Early Sub-Boreal periods is characterized by a distinct Ulmus-fall - though less strong than in Scanodanian diagrams depending on the more limited occurrence of this tree in the region. For the most part climax forest conditions continued to prevail during the earlier and middle part of the Early Sub-Boreal period. However, there was a continuous increase of Quercus in the broad-leaved forests, and Ulmus and Tilia became simultaneously successively decreased. During the middle part of this period forests of Pinus and Betula appear to have had their minimum distribution.

From about the later part of the Early Sub-Boreal period the development became obviously changed. From this time and onwards during the Late Sub-Boreal period Quercus shows a distinct and continuous decrease. The decrease of Ulmus and Tilia is further continued, and accompanied by a slight but distinct decrease also of Corylus. Thus, the general feature of the vegetational development is a beginning continuous decrease of the broad-leaved tree forest constituents, which is compensated for by a corresponding increase of Betula and in part also Pinus.

This retrogression of the broad-leaved forest should be connected with the beginning climate deterioration. The change in climate has occasioned a general decrease of the nemoral broad-leaved trees in favour of in the first place Betula. The increased humidity ought to have initiated an accelerated soil leaching, and besides a direct climatic influence also such an edaphic change may have influenced the development. In the sense of Iversen (1964) the indicated development represents the beginning of the Post-Glacial retrogressive vegetational succession. Around the transition between the Early and Late Sub-Boreal periods, scattered stands of Fagus and Carpinus may have immigrated into the region.

During the Early Sub-Boreal period primitive agriculture and stock-raising were introduced into Scandinavia by immigrating Neolithic peoples, and from then on the human interference also must be considered in the interpretation of the vegetational development. The central South Swedish Highlands have represented a marginal area to the richer settlement in Scanodania. However, an Early Neolithic land occupation is actually possibly faintly indicated in the pollen diagram from Lake Trummen.

Indications of an increased human influence are found onwards during the later part of the Early Sub-Boreal period, which may be connected with the Middle Neolithic Battle Axe culture. An indicated, further expansion of the settlement is found during the beginning of the Late Sub-Boreal period, which archaeologically corresponds to the Late Neolithic and the beginning of the Bronze Age. The Late Neolithic is archaeologically known to have been distinctly expansive in the central South Swedish Highlands.

The retrogressive succession was continued during the Early and Late Sub-Atlantic periods. The human influence on vegetation was successively increased. Due to the partly rather poor representation of these periods in the pollen diagrams, the development unfortunately cannot be followed in particular details. However, among the broad-leaved trees Ulmus, Tilia and Fraxinus became further decreased. Quercus appears to have had a somewhat different development in that there was a renewed increase towards a second maximum during the Early Sub-Atlantic period. However, thereafter also Quercus shows a distinct and successive decrease.

The increased spreading of Fagus and Carpinus and the beginning immigration of Picea during the Early Sub-Atlantic period implied an im-

portant vegetational change. The spreading constituted a further stage in the retrogressive succession. Fagus was culminating during the earlier part of the Late Sub-Atlantic period and was then successively decreasing. Picea shows a mainly continuous increase. Carpinus is represented only in low frequency and culminates already during the Early Sub-Atlantic period.

The increased human settlement appears from the successively richer occurrence of apophytes and anthropochors. However, first during the course of the Late Sub-Atlantic period - archaeologically during the Viking period and the beginning of the Middle Age - the human interference in vegetation became a really important factor, which as indicated by a strong Juniperus increase, has resulted in a more pronounced opening of the forest landscape. The human interference has acted towards an acceleration of the retrogressive development. The landscape development during the latest centuries has been followed on the basis of some available older maps and written sources.

Remarks on the main features in the vegetation development

von Post (1944, 1946) has pointed out the climate conditioned regional parallelism and reversion in the Post-Glacial forest development. Later on Iversen (1954, 1958) has emphasized that besides the climate also the soil development and the competition for light are likely to have influenced the vegetation succession. Both the climate conditioned reversion in the development stressed by von Post, and the relationship between climate, vegetation and soil stressed by Iversen may be illustrated in the simplified pollen diagram in Fig. 4.

The indicated period I corresponds to the end of Iversen's (1958) protocratic stage. This stage has also comprised the whole preceding Late-Glacial time, which however is not represented. As described by Iversen, virgin and unleached, neutral or basic, mineral soils were exposed when the ice receded. The light was ample. Due to the climate and the edaphic conditions calciphilous, light-demanding and low-competitive plants were favoured in the first immigrating vegetation. Principally the same conditions and the same development have certainly characterized the present investigation area. At the beginning of Post-Glacial time, as described, a pioneer forest vegetation of Betula was rapidly immigrating. However, the forests were in the beginning more or less open, and survivals from the Late-Glacial vegetation persisted in places. According to Iversen also the Pre-Boreal period ought to be rec-

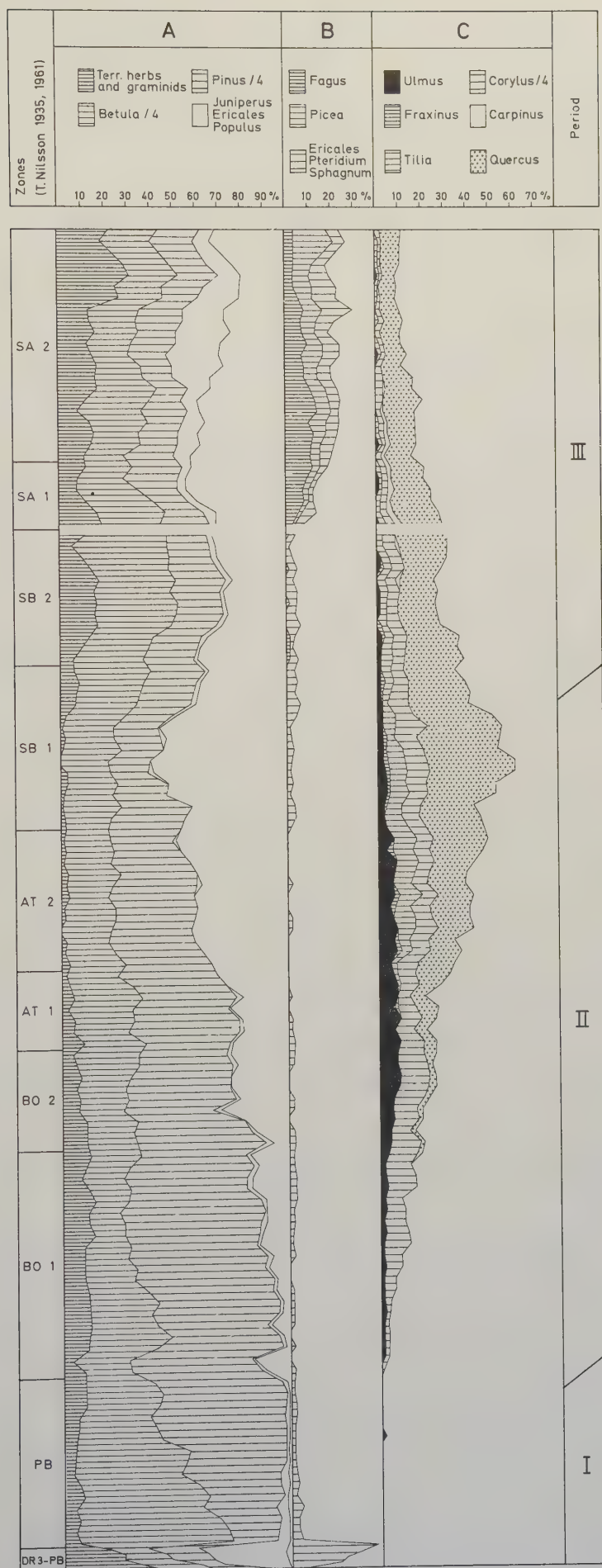


Fig. 4. Simplified pollen diagram showing the main features in the Post-Glacial vegetational development in the investigation area. The zone sequence PB-SB 2 originates from the main diagram, the zone sequence SA 1-2 from the complementary diagram. The terrestrial spermatophytes form the basic sum. *Alnus*, *Betula*, *Corylus* and *Pinus* are divided by 4. The diagram is constructed according to the scheme used by Andersen (1964, 1965, cf. Berglund 1966 b). Part A comprises plants which do not tolerate well competition and shade, part B plants indicative of acid humus or peat (raw-humus), part C plants characteristic of fertile soils (mull).

known to the protocratic stage. The indicated period II corresponds to the mesocratic stage, which comprises the greater part of Post-Glacial time, i.e. the Boreal, the Atlantic and the Early Sub-Boreal periods. The climate reached an optimum. Mature, neutral or slightly acid soils were probably developed in the region. Quercetum Mixtum and Corylus which prefer and are characteristic of fertile mull soils are shown in part C in the diagram. The forests developed as described towards climax forests. The maximum forest covering of the landscape and the maximum shade were reached during the mesocratic stage. Period III which comprises the Late Sub-Boreal and the Sub-Atlantic periods, corresponds to the beginning of the telocratic stage. The increased humidity in connection with the climate deterioration initiated during this stage an accelerated leaching and soil degradation. This edaphic change together with a direct climatic influence, as stressed, has caused an opening of the broad-leaved forests in favour of in the first place Betula. Furthermore, the expansion of Picea and Fagus, which is shown in part B in the diagram, is a characteristic feature of the telocratic stage. Particularly the increased spreading of Picea has contributed to a further increased soil leaching.

Roughly the same period boundaries can be used to illustrate the reversion in the development emphasized by von Post. The periods I and III correspond to the periods of increasing and decreasing temperature respectively, during which the terminocratic elements - Pinus and Betula shown in part A in the diagram - have culminated. Period II corresponds to the period of maximum temperature, which according to von Post is characterized by the culmination of the mediocratic elements Quercetum Mixtum and Alnus (the latter one not represented in the diagram).

II INVESTIGATION ON THE WATER LEVEL DEVELOPMENT

The water level development in Lake Trummen

The water level changes which have been established in Lake Trummen in all probability can be proposed to have been primarily climatically conditioned. Besides being important for a correct interpretation of the palaeolimnologic development the investigation on the water level development has contributed to the knowledge of the major trend of climatic changes during Post-Glacial time.

The investigation on the water level development in Lake Trummen has been based on macrofossil analysis of 7 pollen-analytically correlated profiles. The situation of the profiles appear from the map in Fig. 5

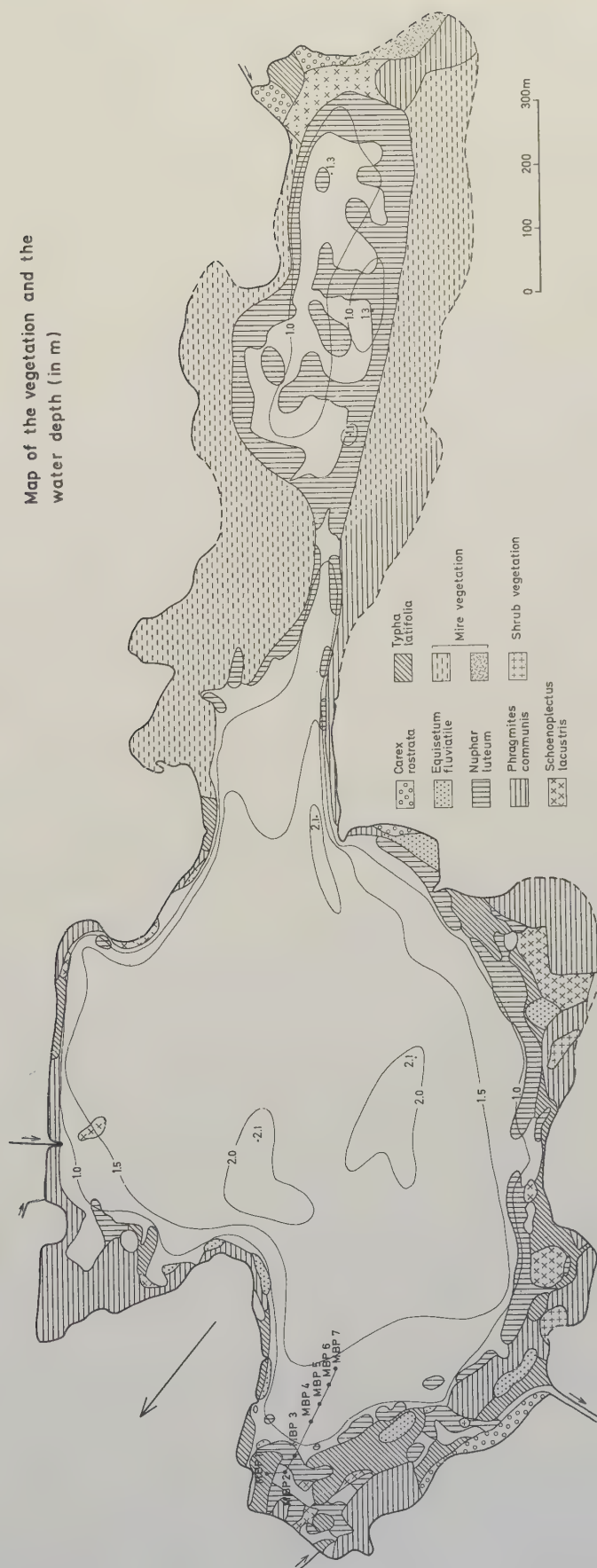


Fig. 5. Map of Lake Trummen showing the macrophyte vegetation and the water depth. The profiles MBP 1 - MBP 7 on which the investigation on the water level development is based, are indicated.

which shows also the vegetation and the water depth in the lake. The principle in the interpretation of the macrofossil diagrams is that fluctuations of the water level will have occasioned changes in the distribution of the lake vegetation - an outward spreading during a lowering, a backward displacement during a rise of the water level - and these vegetational changes can generally be easily established and followed on the basis of the seed- and fruit-curves in the diagrams.

The analysis has also comprised a determination of the amount of coarse matter - coarse detritus and coarse minerogenic matter - which often appears to be a valuable complement to the real macrofossil analysis. The principle in the interpretation is that sediments deposited in shallow water close to the shore generally will contain a larger amount of coarse detritus and/or coarse minerogenic matter than sediments deposited in deeper water. The amount of coarse matter can in that way be used as an indication of the relative water depth and the situation relative to the shore. The macrofossil diagrams MBP 4, MBP 5, MBP 6 and MBP 7 are presented in Figs. 6-7, and the correlated profile section MBP 1 - MBP 7 in Fig. 8.

Two major lowerings of the water level have been established. The older lowering is registered in diagrams MBP 5, MBP 6 and MBP 7 by a distinct coarse matter increase, which culminates evidently during the earlier part of the Early Boreal period. In the inner diagrams this lowering corresponds to a comprehensive hiatus, which thus indicates a contemporaneous lowering of the deposition limit. The younger lowering has culminated some time during the later part of the Early Sub-Boreal period and the earlier part of the Late Sub-Boreal period, and is in diagrams MBP 4, MBP 5 and MBP 6 registered likewise in the first place by an increase of the coarse matter content. In the inner diagrams MBP 1, MBP 2 and MBP 3 the contemporaneous lowering of the deposition limit has occasioned a comprehensive hiatus. Each lowering has been succeeded by a distinct major rise of the water level.

The water level development in Lake Trummen compared to the development established in other lakes

The comparison comprises only some later investigation. Several older investigations have been presented (e.g. Sundelin 1917, Lundqvist 1925), but unfortunately these are judged by modern standards of exactness rather out-of-date, owing to the then limited possibilities of a more precise dating.

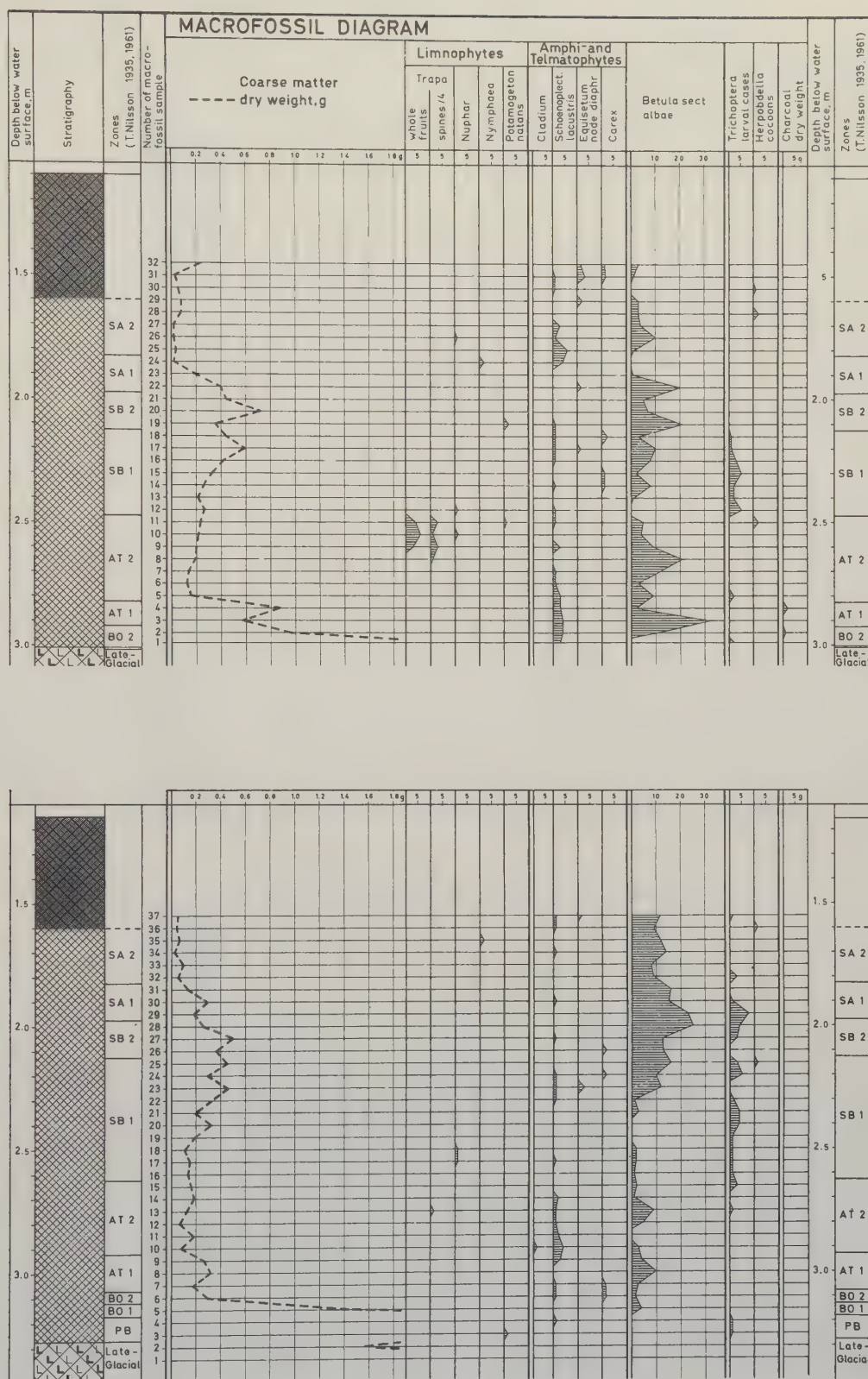


Fig. 6. Macrofossil diagrams MBP 4 (above) and MBP 5 (below). The frequencies in the macrofossil diagrams are given in absolute values per 600 cm³ - the large-capacity sampler designed by the present author (Digerfeldt 1965) has been used. The indicated uppermost gyttja represents the FeS-coloured gyttja deposited during the recent pollution period. The Late-Glacial sediment in the lower part of the profiles is silty clay gyttja.

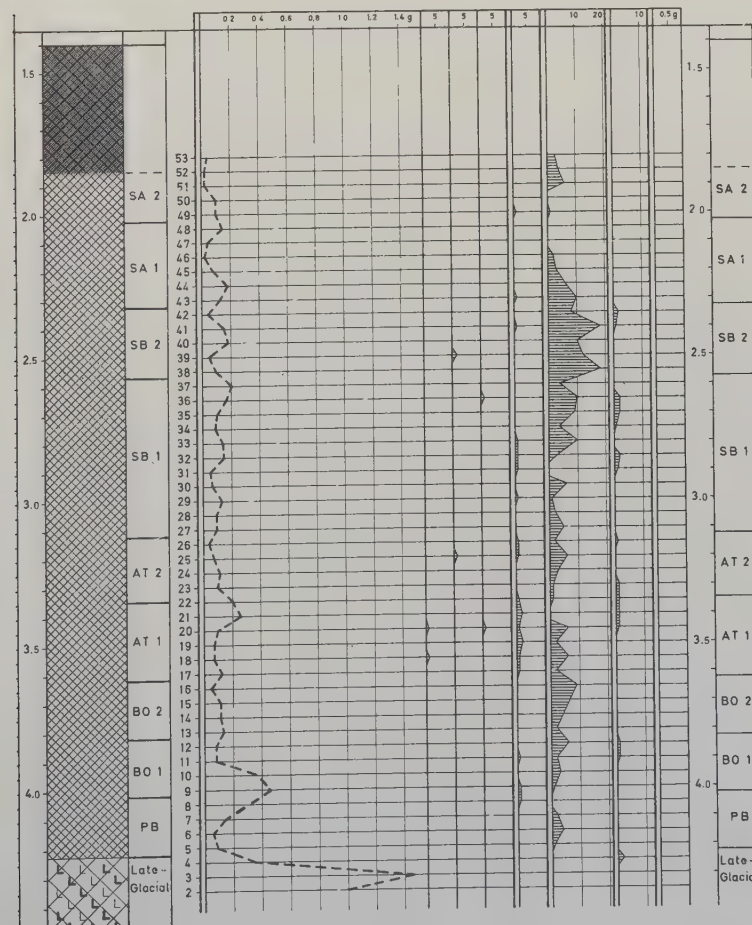
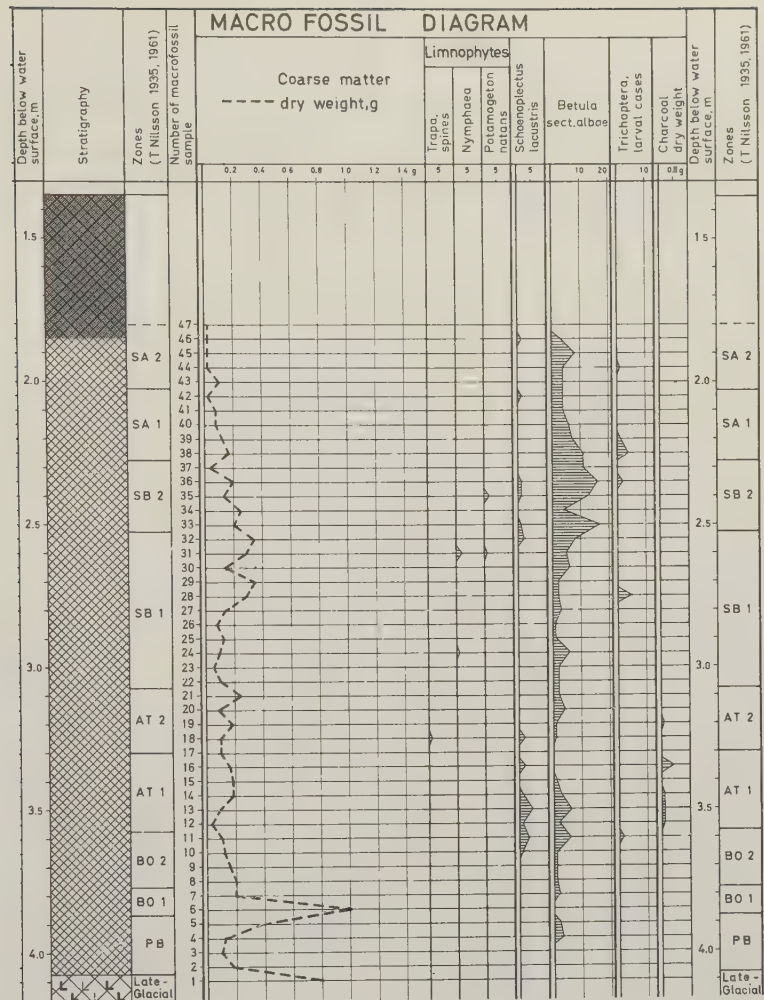


Fig. 7. Macrofossil diagrams MBP 6 (above) and MBP 7 (below).

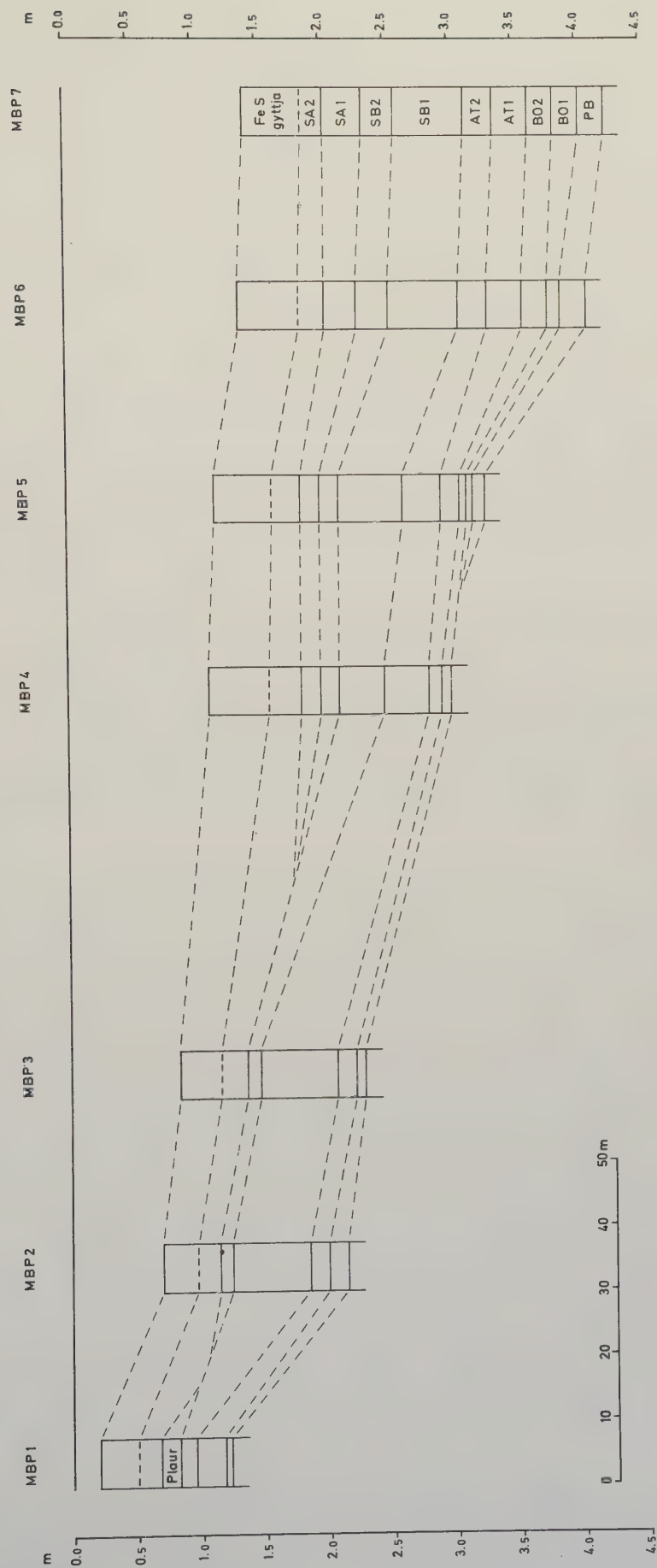


Fig. 8. Correlated section of the profiles MBP 1 - MBP 7.

Jørgensen (1963) has presented an investigation of the ancient lake in the bog Aamosen (West-Zealand, Denmark), which thoroughly treats the water level development during the Pre-Boreal, the Early and Late Boreal and partly also the Atlantic periods. A lowering of the lake water level was established to have taken place during the Early Boreal period (zone V in the Danish zone system by Jessen 1935, and revised according to Jørgensen 1954). The lowering was succeeded by a rise around the transition to the Late Boreal period (zone VI). This rise continued during the earlier half of the Late Boreal period, as was confirmed both from indicated vegetational changes and from a demonstrated plaur formation. Around the middle of the Late Boreal period a halt seems to have occurred, however the rise was then resumed and culminated shortly before the transition between the Late Boreal period and the Atlantic period (zone VII).

Investigations dealing with the water level development in Aamosen have also been presented by Troels-Smith (1943). Though partly less detailed the results principally agree with those given by Jørgensen. In addition Troels-Smith states that there are indications of a strong drying-up during the Sub-Boreal periods (zone VIII), which then during the Sub-Atlantic periods (zone IX) was succeeded by a renewed water level rise.

In the pollen-analytical investigation of Scanian bogs and ancient lakes presented by T. Nilsson (1935), part of the comprehensive stratigraphic material was used for conclusions also on the water level development. In some of the lakes and ancient lakes a hiatus, or an otherwise demonstrated lowering of the deposition limit, was described to indicate the occurrence of a water level lowering during older Post-Glacial time. The probable culmination of the lowering was dated to the Late Boreal period. A temporary rise was found during the beginning of the Early Atlantic period, but the development onwards during the Early and Late Atlantic periods could not be certainly and more precisely established. The interpretation of the water level development during younger Post-Glacial time was based largely on recurrence surfaces in raised bogs. However, in some lakes a rise of the water level is indicated from around the transition between the Early and Late Sub-Boreal periods and onwards.

In some later investigations T. Nilsson (1964 b, 1967) has in greater detail treated the development in the ancient lake Ageröds mosse, and in these the interpretation of the water level development during older

Post-Glacial time is somewhat revised. Besides the previously established lowering during the Late Boreal period, there are found indications of one older lowering during the Early Boreal period. The generally lower thinning-out of the gyttja deposited during the Pre-Boreal and Early Boreal periods may indicate that this older lowering actually has been the stronger and more important one. The gyttja deposited during the Late Boreal period is described to be generally distinctly transgressive. Already in the investigation presented in 1935, this older lowering may actually be found indicated. In several of the then described ancient lakes - i.e., in the bogs Baremosse, Holmö mosse, Herrevadsklosters mosse, Getings mosse and Fjällmossen there can thus be seen also an older hiatus comprising parts of, or the whole of, the Early Boreal and Pre-Boreal periods. The subsequent renewed deposition in these lakes indicates a general rise of the water level during the Late Boreal period.

Though the precise dating is slightly different, the lowering established by Jørgensen in Aamosen and by T. Nilsson in Ageröds mosse may be connected with the older major lowering established in Lake Trummen. The lowering in Ageröds mosse during the Late Boreal period, like the fluctuations indicated during this period in Aamosen, may then probably represent water level changes of smaller amplitude, which certainly also must have occurred. The ancient lake in both Ageröds mosse and Aamosen has been shallow, and accordingly the conditions have been favourable for a distinct registration also of such smaller water level fluctuations.

From the hypothetical water level curve presented by T. Nilsson (1967), the rise which succeeded the lowering during the Early Boreal period should have continued - possibly in fluctuations - until about the latter part of the Early Atlantic period. Thereafter a renewed lowering is indicated, culminating probably during the Late Atlantic period. T. Nilsson considers it unlikely that there has been any particularly marked further lowering and drying-up during parts of the Sub-Boreal periods. In the hypothetical curve given from Ageröds mosse there is indicated a succeeding continuous - though fluctuating - rise of the water level already from the Early Sub-Boreal period. However, in this case the interpretation according to the opinion of the present author is actually not particularly well supported. The ancient lake in Ageröds mosse became overgrown during the Early Atlantic period, and it cannot be excluded that quite local conditions from then on partly have in-

fluenced the development. More positive proofs of a water level rise are not found until during the Late Sub-Boreal period. From the development established in Lake Trummen, it must be considered quite clear that a marked lowering has culminated around the transition between the Early and Late Sub-Boreal periods.

In an investigation on the Post-Glacial vegetation development on the Great Alvar of Öland Königsson (1968) has presented a comprehensive lake stratigraphic material. In most of the investigated lakes an older hiatus indicates the occurrence of a low water period during older Post-Glacial time. A more precise dating appears unfortunately not to be possible. The hiatus covers the Pre-Boreal period and part of - in some cases the whole of - the Early Boreal period. In several lakes a succeeding rise of the water level is indicated already during the latter period. Königsson describes a younger hiatus covering the Atlantic period and at least the beginning of the Sub-Boreal period (Königsson has applied the Danish zone system according to Jessen 1935, in which the Atlantic and Sub-Boreal periods are not further divided). Also this hiatus is found in most of the investigated lakes, and it is interpreted as probably caused by an oxidizing of previously deposited gyttja during a low water period during "the most continental parts of the Sub-Boreal period" (Königsson op.cit. p.141). As stressed by Königsson the correlation of the profiles are sometimes complicated due to the strong compression of the layer sequence, and possibly the younger hiatus comprises a somewhat larger part of the Sub-Boreal period. Actually in that case the drying-up indicated in the Alvar lakes may correspond to the younger water level lowering established in Lake Trummen.

In the bay Ranviken in Lake Immeln, Scania, the present author has carried out a similar investigation on the Post-Glacial water level development as in Lake Trummen (Digerfeldt 1966, 1971 a). Exactly the same development as in Lake Trummen has been established. One older, major lowering of the water level has culminated during the earlier part of the Early Boreal period, and another younger lowering around the transition between the Early and Late Sub-Boreal periods.

The present author has also thoroughly investigated the water level development - both the Late-Glacial and the Post-Glacial - in the ancient lake at Torreberga, Scania (Digerfeldt 1970, 1971 b). Also there is in principal a similar Post-Glacial development indicated. However, the older lowering corresponds to a comprehensive hiatus comprising the Early and Late Boreal periods, and cannot unfortunately be more precisely dated. The culmination of the younger lowering has been dated to

the earlier or middle part of the Early Sub-Boreal period, which is thus somewhat different from in Lake Trummen and in the bay Ranviken, Lake Immeln. The different dating may in this case be partly explained by the difficulties in correlating the locally influenced and disturbed pollen diagrams, partly by the probability that local conditions have influenced the water level development. The definite overgrowing of the ancient lake occurred in connection with this younger lowering.

Water level changes in lakes as evidence on climatic changes

As climatic evidence a water level change indicates a change of the humidity. The cause of a humidity change may partly be a change in precipitation, partly a change in temperature. An increase in precipitation associated with a fall in temperature will occasion a maximum rise of the water level and a decrease in precipitation associated with a rise in temperature will occasion a maximum lowering of the water level. Roughly speaking, a change of the climate in a maritime direction will lead to a rise of the water level, a change in a continental direction to a lowering. However, a change of the humidity may just as well be the result of changes in either precipitation or temperature alone. A water level fluctuation indicates that a change in the humidity of climate has occurred but actually nothing about the conditioning factors temperature and precipitation.

The water level development established in Lake Trummen, and the essentially agreeing development in the lakes and ancient lakes referred to in the comparison, indicate a major change of the humidity of climate in principle corresponding with the original Blytt-Sernander climatic scheme. This scheme is no doubt schematic, and through later investigations it has been revised. Actually, however, during Post-Glacial time there can evidently be distinguished two major low water periods indicating a relatively drier climate, and two major high water periods indicating a relatively moister climate. An important revision of the Blytt-Sernander scheme is the establishing of the several minor fluctuations, which have modified the major trend of climate changes. Furthermore the change in the character of climate seems not to have been as simple as originally proposed.

The younger dry period, which, from the investigation in Lake Trummen, seems to have culminated around the transition between the Early and Late Sub-Boreal periods, may be connected with a commonly proposed change in climate in a continental direction, beginning during the for-

mer period. In Lake Trummen a beginning decrease of the water depth is indicated already during the later part of the Late Atlantic period. However, it cannot be concluded if the lowering of the water level has begun already then, since the decrease in water depth in part also may be an effect of a natural filling-up. Evidence on the change in climate in a continental direction during the Early Sub-Boreal period are, among others, Iversen's (1944) investigation on Hedera, Viscum and Ilex, von Post's (1925) on Trapa and Cladium, and Degerbøl's & Krog's (1951) on Emys orbicularis. The succeeding rise, which began already during the Late Sub-Boreal period, registers the beginning climate deterioration, proceeding in fluctuations and, as proposed, involving both an increase in precipitation and a decrease in temperature.

The climatic interpretation of the older dry period, during the Early Boreal period, is much more complicated. In the ancient lake at Torregberga, mentioned in the comparison, the present author has established a beginning lowering of the water level already during the later part of the Pre-Boreal period (Digerfeldt 1971 b). In Lake Trummen the older lowering was succeeded by a major rise of the water level already during the later part of the Early Boreal period. In the Aamosen investigation Jørgensen, by a close analysis of the occurrence of Hedera, Viscum and Cladium, found indications of some evidently minor changes in temperature and precipitation during the Late Boreal period. On the whole however, vegetational evidence on climate changes during these older periods are unfortunately very sparse. The strong drying may be an effect of the rapid and strong increase in temperature possibly in combination with a decrease in precipitation, while the succeeding water level rise and indicated humidity increase may be an effect of a change mainly in precipitation. Proper evidence or indications of the character of climate may be brought forth in future investigations.

III. INVESTIGATION ON THE PALAEOLIMNOLOGIC DEVELOPMENT

The limnologic character of a lake within the temperate climate zone is not definite once and for all. From the time of their origin all lakes have been subjected to a limnologic development. For the most part rather slow but continuous changes have taken place, which more or less noticeably have altered the limnologic character.

The aim of palaeolimnologic research is to investigate as thoroughly as possible this limnologic development of lakes. The research is car-

ried out by means of different kinds of analyses of the sediments which during the development have been deposited in the lakes.

The limnologic character of a lake is determined primarily by the geological and geochemical nature of the surroundings. The specific characteristics of lakes are reflected and expressed in the chemical and physical water conditions - the environmental conditions - and the organism conditions. In limnologic research the environmental analyses and the organism analyses represent the base for the characterization and the typologic grouping of lakes. In palaeolimnologic research the latter analyses correspond to microfossil and macrofossil analyses - analyses of determinable remains of plants and animals which have existed in the lakes and which have been preserved and recorded in the sediment. To be sure, a number of organisms must have been decomposed totally after dying, or to such an extent that they cannot be identified. However, usually there are enough preserved to make possible a satisfactorily certain interpretation of the development.

The environmental analyses in palaeolimnologic research correspond to chemical and physical sediment analyses. A specific geological and geochemical environment gives a lake with specific water and organism conditions. In this lake there will also be formed a sediment with specific chemical and physical qualities. On the basis of chemical and physical sediment analyses therefore, also an interpretation of the environmental development ought to be possible.

The palaeolimnologic investigation in Lake Trummen has comprised chemical sediment analysis and diatom analysis. The sediment samples originate from the same main profile as has been used in the pollen-analytic investigation on the regional vegetation development.

Determination of the rate of deposition

Thanks to the large number of radiocarbon datings, it has been possible to determine with rather great accuracy the rate of deposition during the different periods of the lake development. The deposition rate represents in itself a valuable palaeolimnologic information - the deposition being the result of the total lake metabolism. However, the determination is also necessary for an accurate calculation of the results of the chemical sediment analyses. Thus, if the results are to be comparable and really reliable as a base for the interpretation of the palaeolimnologic development they must be calculated per unit time: This manner of calculation presupposes a satisfactorily thorough determination of the deposition rate.

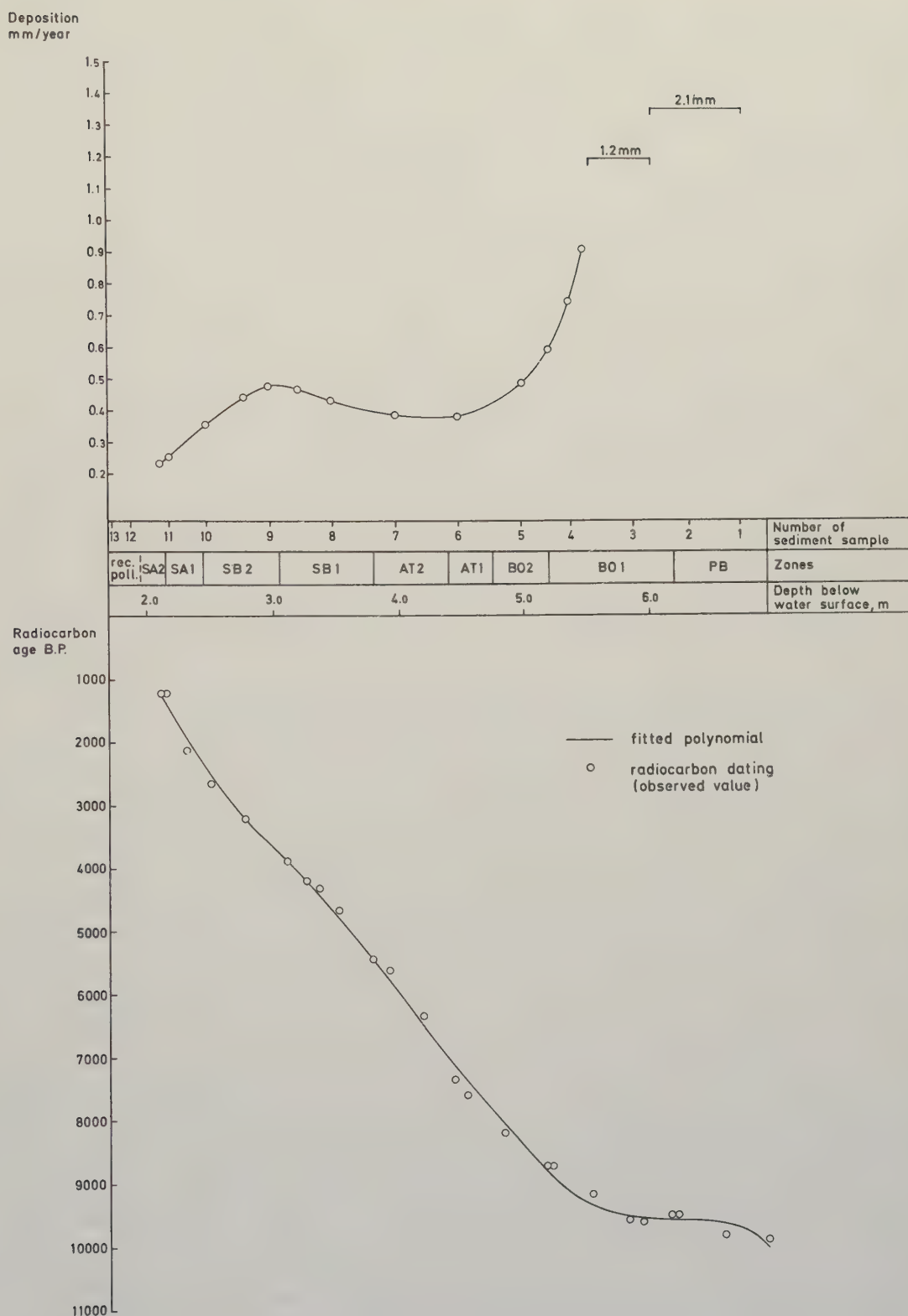


Fig. 9. Lower diagram: The radiocarbon datings in the main profile and the fitted polynomial. Upper diagram: The rate of deposition calculated from the fitted polynomial. The separate rates for zone PB and the earliest part of zone B0 1 are mean values calculations.

In the lower diagram in Fig. 9 the available radiocarbon datings are plotted against the depth below sediment surface. By computer processing a regression analysis was carried out with the age as a function of the depth. A 5th degree polynomial was fitted to the available data. By inverting the derivate of the polynomial, the sought rate of deposition has been obtained.

The deposition rate during the different periods of lake development calculated by use of this polynomial are presented in the upper diagram in Fig. 9. The uppermost c. 40 cm of the profile have not been included in the data processing. The greater part consists of FeS-coloured gyttja deposited during the recent pollution period, which can be pollen-analytically dated in the same way as in the profile described in the restoration report (Digerfeldt 1969). The uppermost c. 20 cm of the FeS-coloured gyttja can be calculated to have been deposited at a mean rate of c. 8 mm/year, the lowermost c. 5 cm at a mean rate of c. 1.3 mm/year. The mean rate for the whole pollution period will be c. 3.8 mm/year.

In the lowermost part of the profile probably methodic errors unfortunately have influenced the radiocarbon dating, which then also excludes the use of the fitted polynomial for any reliable calculations of the deposition rate. To get an at least approximate determination the mean rate of deposition in the lowermost part of the profile was calculated by use of the separate datings or means of datings. This gave for the part of the Pre-Boreal period in question a mean rate of c. 2.4 mm/year, for the part of the Early Boreal period in question c. 1.2 mm/year.

Sediment Analysis

The sediment chemical investigation has comprised determination of loss on ignition, organic carbon, Kjeldahl-nitrogen, total phosphorus and total iron, alkali-soluble silica, extractable sodium, potassium, magnesium, calcium and iron.

The determinations of the total organic matter by loss on ignition, the organic carbon and Kjeldahl-nitrogen provide the base for the interpretation of the development of the productivity. The primary production is determined by the amount of available mineral nutrients and within the range concerned here by the temperature. Part of the organic production will become subjected to decomposition and mineralization, and so continuously re-enter into the metabolic circulation. The most

intense decomposition occurs during the sedimentation and in the surface sediment. In deeper sediments the once preserved amount of organic matter can be presumed to remain largely unchanged.

The part of the organic production which will become preserved in the sediment is determined by several factors. The temperature and oxygen conditions and the morphometric conditions determine together the extent and the rate of the decomposition during the sedimentation and in the surface sediment. Thus, the relation between the organic deposition and the actually developed production varies in lakes of different types and during different temperature conditions. Owing to changes in the determining factors the relation certainly has varied also during the course of the development in one and the same lake. However, as concerns the present Post-Glacial development of Lake Trummen it may be supposed that these changes have not been of such a degree, that they more seriously restrict the comparability of the calculated annual amounts and the possibilities of palaeolimnologic interpretation. The possible influence by changes in temperature has been discussed. Thus, the found changes of the organic deposition probably correctly indicate the general changes of the productivity that have occurred during the lake development.

The changes in the amount total organic matter, organic carbon and Kjeldahl-nitrogen calculated per annual deposition appear from the diagrams in Fig. 10. Disregarding the recent pollution period, the highest productivity is indicated to have been reached during the Pre-Boreal period. A succeeding distinct decrease occurred during the Early and Late Boreal periods. From the Early and Late Atlantic periods onwards until the recent pollution period the productivity appears to have become only moderately changed. However, a slight but significant increase is indicated during part of the Early and Late Sub-Boreal periods. The increase of the productivity during the recent pollution period is striking. At the evaluation of the amount organic matter in the FeS-coloured gyttja a certain loss by further decomposition must be considered.

The changes during the development of the amount total phosphorus (Fig. 10) and extractable sodium, potassium, magnesium and calcium calculated per annual deposition follow largely the deposition rate - thus, there is partly a direct relation between these amounts and the annual deposition. However, in the case of phosphorus a higher concentration of this element in the lake during the Pre-Boreal period and the earlier part of the Early Boreal period also seems to be indicated. The amount

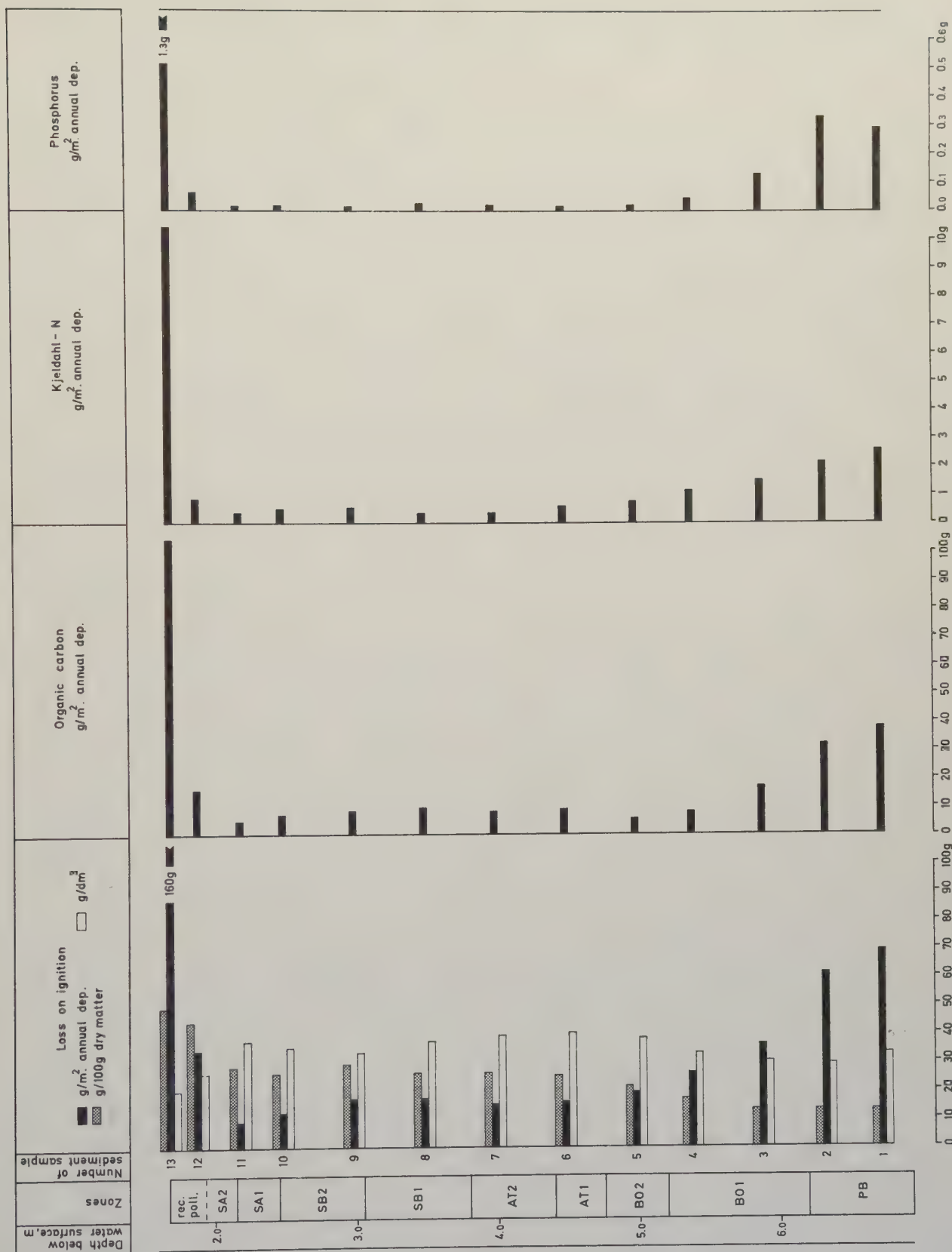


Fig. 10. Diagrams showing the changes in the loss on ignition, organic carbon, Kjeldahl-nitrogen and total phosphorus per annual deposition. The changes in the loss on ignition are shown also calculated per unit dry matter and unit volume.

phosphorus per volume in the gyttja deposited during these periods is distinctly higher than onwards. As concerns the other elements the problems about possible concentration changes in the lake water during the development has been left open.

As concerns iron, the supply of this element probably in the first place has been determined by the inflow of subsoil water into the lake. The minerogenic bottom - sand and silt - which existed in large parts of the lake during the beginning of the Pre-Boreal period, can be supposed to have been rather easily permeable to subsoil water. A strong iron deposition, indicates a large inflow into the lake then. From the Pre-Boreal period and onwards the proceeding deposition of compact gyttja has occasioned a more effective tightening of the minerogenic bottom, which accordingly also has implied a successively stronger blocking and decrease of the subsoil water inflow. In agreement with this the precipitation of iron during the further development shows a strong and continuous decrease.

Diatom Analysis

The microfossil analysis has comprised only diatom analysis. The diatoms represent an organism group with an ecology that at least partly is rather well known. The diatoms have been used as indicators of in the first place lake water pH. The grouping of the diatoms in respect to their known pH requirement has followed the system employed by Hustedt (1939). The changes in the representation of the different pH groups during the development appear from the diagram in Fig. 11.

The possibilities of interpreting the calculated spectra in terms of actual pH intervals can be discussed. In most cases it may be sufficient and most advisable to restrict the interpretation to concern only the direction of the development, as indicated by the changes in the diatom flora. In Lake Trummen the distinct decrease of the alkaliphilous forms and the corresponding distinct increase of the indifferent and acidophilous forms indicate a development towards a successive decrease in pH from the Pre-Boreal period until the earlier part of the Early Sub-Boreal period. A temporary slight increase in pH occurred possibly during the later part of the Early Sub-Boreal period and the earlier part of the Late Sub-Boreal period, as indicated by a temporary increase of the alkaliphilous forms and decrease of the acidophilous forms found at that time. The increase in pH which the recent pollution has caused is distinctly registered.

The diatom-analytical results have also been calculated according to the method proposed by Nygaard (1956), and the reliability of this method has been discussed.

Depth below water surface, m	Zones	Number of sample	Acidophilous and acidobiontic	Indifferent	Alkaliphilous and alkalibiontic
			% ind.	% ind.	% ind.

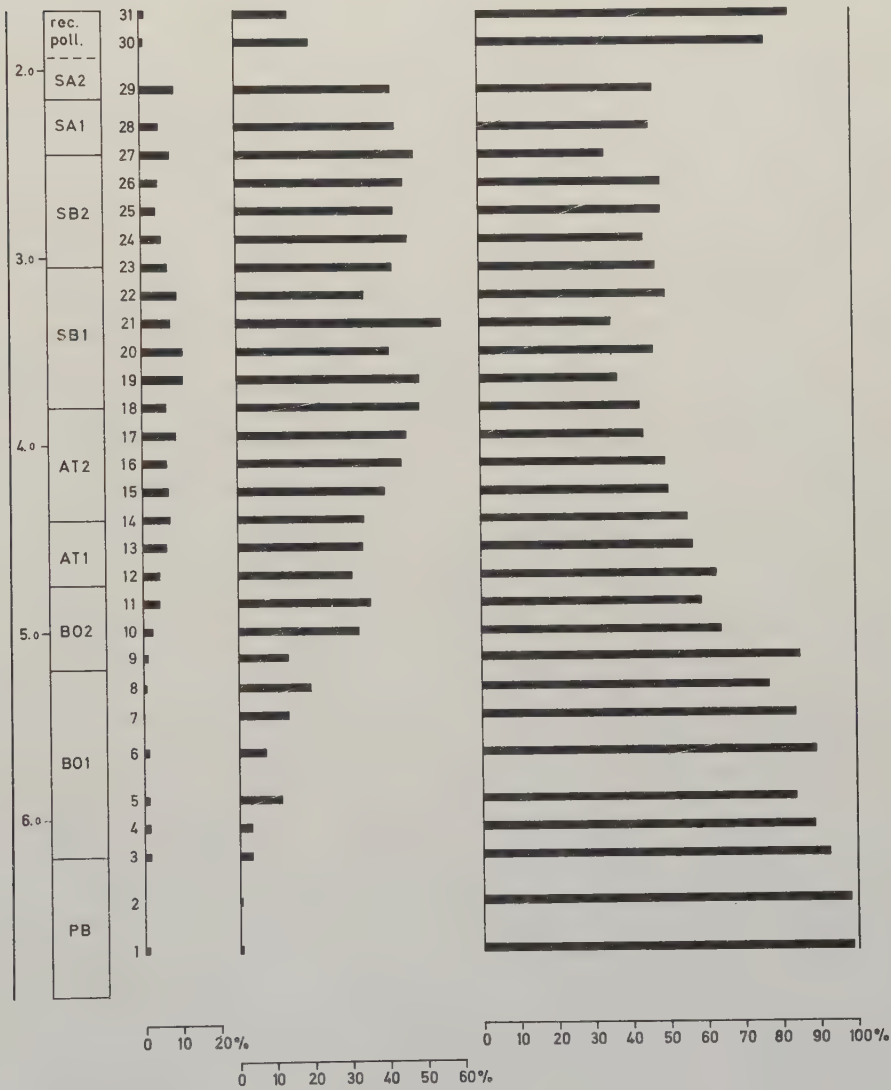


Fig. 11. Diagram showing the changes in the representation of acidophilous and acidobiontic, indifferent, and alkaliphilous and alkalibiontic diatom forms.

Remarks on the main features in the lake development

The development of Lake Trummen during Post-Glacial time has implied a largely continuous decrease of the productivity. The cause of this decrease of the productivity in all probability must be found in an occurred decrease of the supply of mineral nutrients. In the case of phosphorus actually a decreased supply is indicated, in the case of potassium, calcium, magnesium and sodium the problem about possible changes as stressed has been left open. To describe such an occurred decrease of the nutritional standard during the development of a lake Quennerstedt (1955) has proposed the term meiotrophication. For reasons which will be discussed below, the development established in Lake Trummen can actually be presupposed to represent the most natural one - and as was hoped the investigations in this lake may serve as a proper and typical example.

The nutritional standard and the productivity of lakes is determined by the geological and geochemical composition of the soils in the surrounding drainage area. From this area the lakes are by the inflowing water - the surface water and the subsoil water - supplied with mineral nutrients released from the soils by weathering and leaching.

During the Younger Dryas period - as stressed in the remarks on the regional vegetation development - raw and mainly unleached mineral soils can be supposed to have existed in the surroundings of Lake Trummen. The soils were bare or covered with an only sparse tundra vegetation. Due to the probably poor supply of nutrients and due to the climate, the productivity in the lake during the Younger Dryas period ought to have been rather low (cf. Fjerdingsstad 1954, Berglund 1966 a, 1971, Berglund & Malmer 1971).

The improvement of the climate during the transition period DR 3-PB and the beginning of the Pre-Boreal period must have caused a distinct increase of soil weathering and leaching. Besides the direct influence of the rise in temperature, the simultaneous covering of the soils with a denser vegetation and the formation of a more or less acid humus layer has contributed to this increase. Vegetational indications of a soil leaching during the transition period DR 3-PB have been discussed. Thus, though unfortunately not appearing from the present investigation, there ought to have been a distinct increase in the supply of leached minerals from the surrounding soils during the very beginning of Post-Glacial time, which in combination with the commencing more favourable climate conditions has resulted in the indicated relatively high - in

comparison with later on during the development - productivity in the lake.

The indicated succeeding decrease of the productivity must be an effect of the same leaching. As leaching continued, this naturally reduced the primary amount of available leachable minerals in the surrounding soils, and consequently during the course of development there may have occurred a more or less distinct decrease in the amount of mineral nutrients in the inflowing surface water supplied to the lake. The indicated decrease in the supply of phosphorus is particularly important since phosphorus is the nutrient element that - together with nitrogen - commonly determines and regulates the production. The leaching of calcium may have resulted in the contemporaneous successive decrease in pH, which is indicated by the diatom analysis.

This leaching-conditioned decrease of the supply of mineral nutrients generally can be considered as the main cause of the meiotrophication, which as stressed can be supposed to normally have characterized the development of temperate lakes. Besides, as discussed in connection with the description of iron in sediment, the beginning and proceeding deposition of compact gyttja from the Pre-Boreal period and onwards in Lake Trummen has resulted in a more effective tightening of the originally minerogenic bottom. This, accordingly, also has implied a successively stronger blocking and decrease of the inflow of subsoil water richer in mineral nutrients into the lake. Such a development ought to have been common in lakes with a similar bottom. This further decrease in the supply to the lakes may in cases have contributed to accelerate the meiotrophication during particularly the oldest periods of development.

In Lake Trummen a rather stable productivity seems to have been reached during the Early and Late Atlantic periods. The slight but significant increase of the productivity which then occurred during the Early Sub-Boreal period and the earlier part of the Late Sub-Boreal period has been interpreted as a change probably connected with and caused by the local water level development. The marked lowering of the water level which has been established to have culminated around the transition between the Early and Late Sub-Boreal periods has certainly caused an extensive erosion of previously deposited gyttja in shallow water closest to the shore. By this erosion the lake water was then temporarily supplied with mineral nutrients accumulated in this gyttja. Considering the rather small water volume of the lake, this extra supply of nutrients may have resulted in the productivity increase indicated

during part of these periods. Part of the increase may possibly be connected with an occurred expansion of the macrophyte vegetation. As described also a slight increase in pH is indicated by the diatom analysis.

The erosion ceased when the lowering during the Late Sub-Boreal period was succeeded by a renewed water level rise, and then the productivity becomes decreased to about the same level as before. As discussed in the description of the regional vegetation development, from the Late Sub-Boreal period and onwards the deterioration of the climate must have promoted an accelerated leaching and soil degradation. The lowest productivity during the whole lake development is indicated to have been reached around the transition between the Early and Late Sub-Atlantic periods.

The profound change caused by the recent pollution appears distinctly from all analyses. The productivity and the supply of mineral nutrients during this period have become increased to a level never reached before during the natural lake development, and also the pH has become distinctly increased.

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